



High CE technology for HVM EUV source

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When will we reach the end of the tunnel ?



EUV light source development history and schedule

➤ **ETS** **2009-2010**

➤ **10Hz device** **2010-**

➤ **Proto-1** **2011**

➤ **Proto-2** **2012**

➤ **Real-pilot** **2013 -**

EUV light source development history and schedule

➤ ETS

- Max power
- 7hour operation
- Debris mitigation

2009-2010

50W (Clean power @IF, duty2%)

20W (Clean power @IF, duty5%)

➤ 10Hz device

2010-

➤ Proto-1

2011

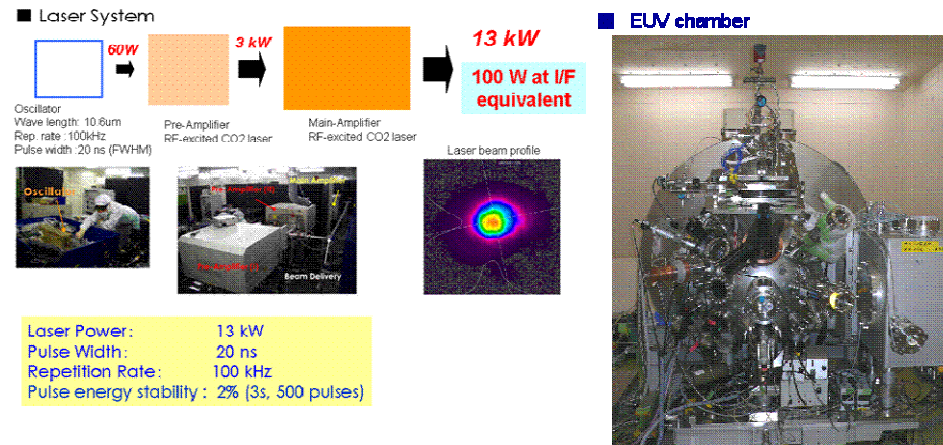
➤ Proto-2

2012

➤ Real-pilot

2013 -

System operation Data (ETS device)



	SPE 2010 (Feb.2010)		EUV Symposium (Oct.2010)	SPE2011 (Feb,2011)
EUV power (@ I/F)	69 W		104 W	42 W
EUV power (clean @ I/F)	33 W		50 W	20 W
Duty cycle	20 %		20 %	5%
Max. non stop op. time	>1 hr		<1 hr	>7 hr
Average CE	2.3 %		2.5 %	2.1%
Dose stability :simulation	(+/- 0.15%)			-
Droplet diameter	60mm		60mm	30mm
CO ₂ laser power	5.6 kW		7.9 kW	3.6kW

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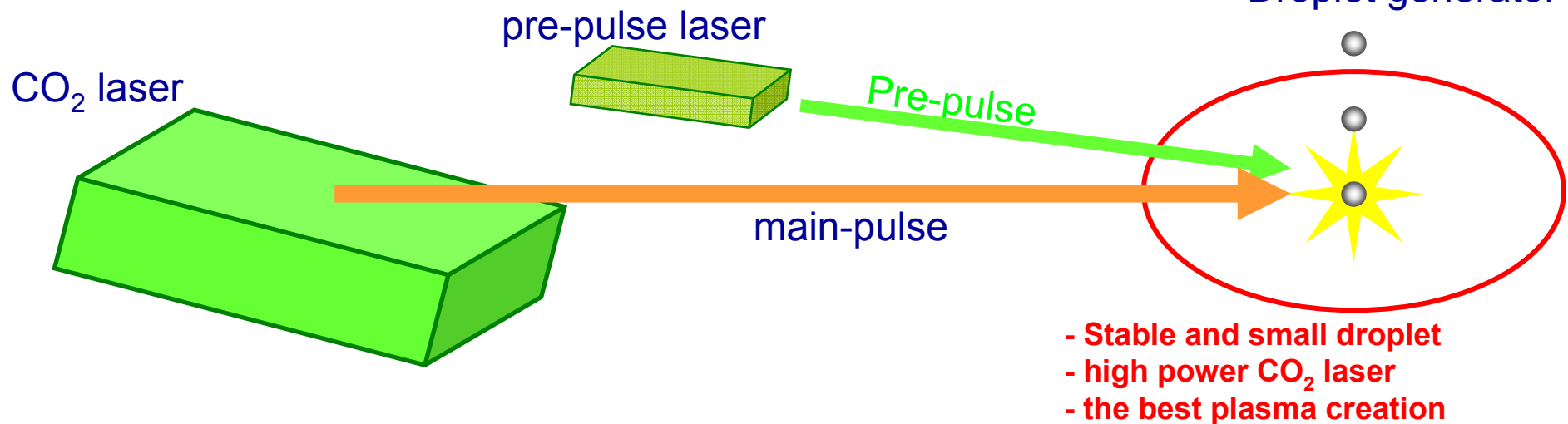
Challenge for CE higher than 5%

3 key challenges

- Small droplet supply with **Droplet on Demand**
- **Dual wavelength Laser Produced Plasma**
- Perfect ionization and **Magnetic mitigation**

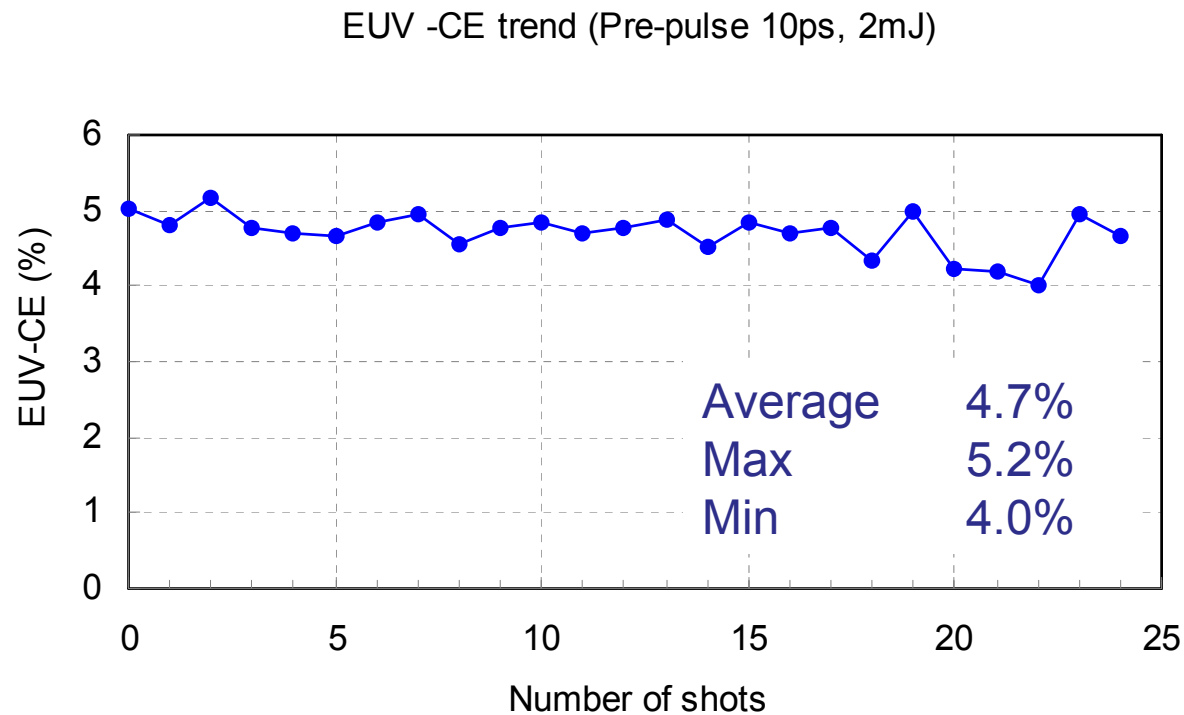


Droplet generator



Technology update: CE improvement

4.7%av. -- highest CE reported to date was demonstrated



Data taken with low rep rate device at 2Hz

Technology update: Mist shape after pre-pulse

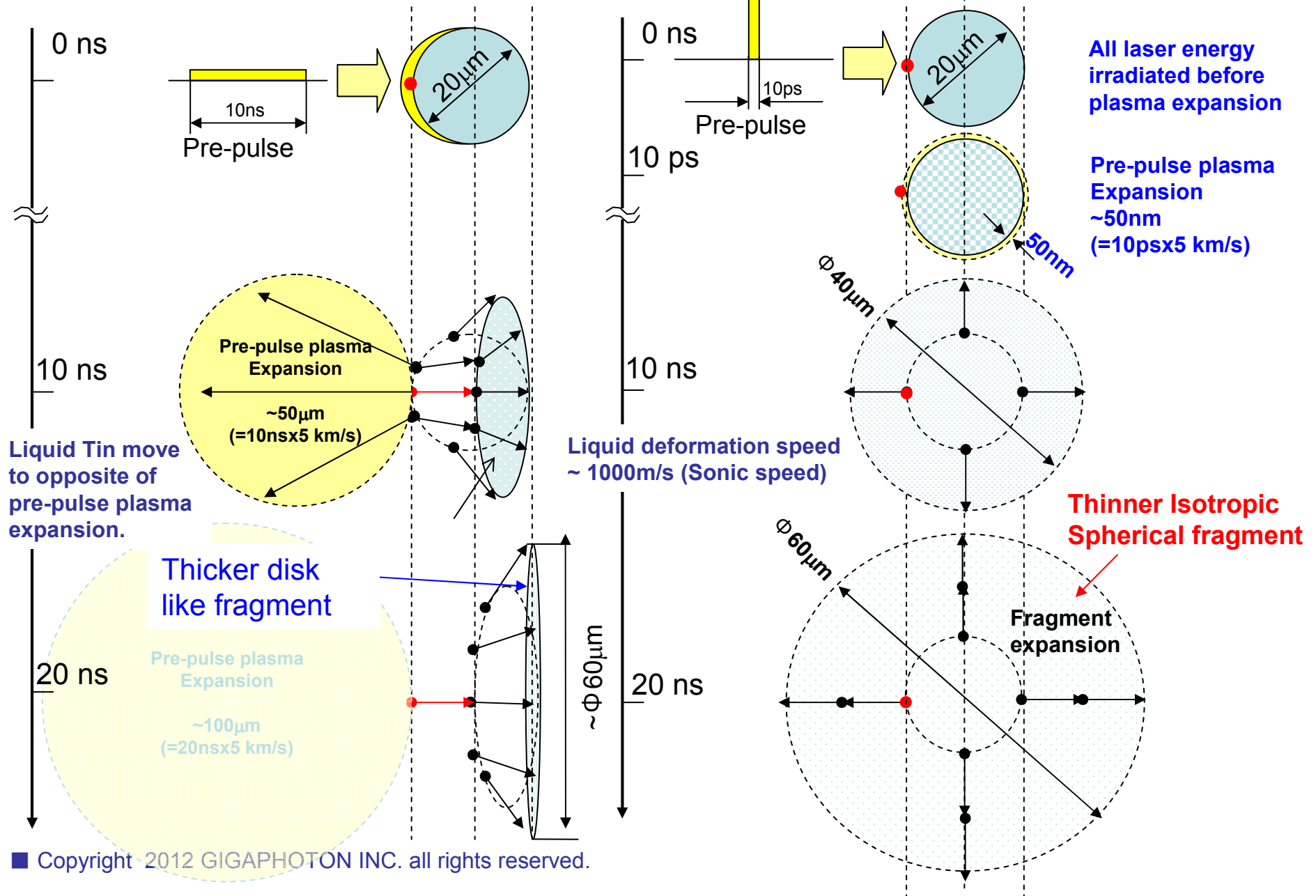
- The mist shape with pico second pre-pulse is different from the one with nano second pre-pulse
 - ✓ ps: dome / ns: thin disk or ring
- This could be a major reason of high CE

	10 ps		10 ns	
Pulse energy	2.0 mJ		2.7 mJ	
delay	1 μ s	2 μ s	1 μ s	2 μ s
60 deg view				
90 deg view				

Simulation of ns pre-pulse irradiated target



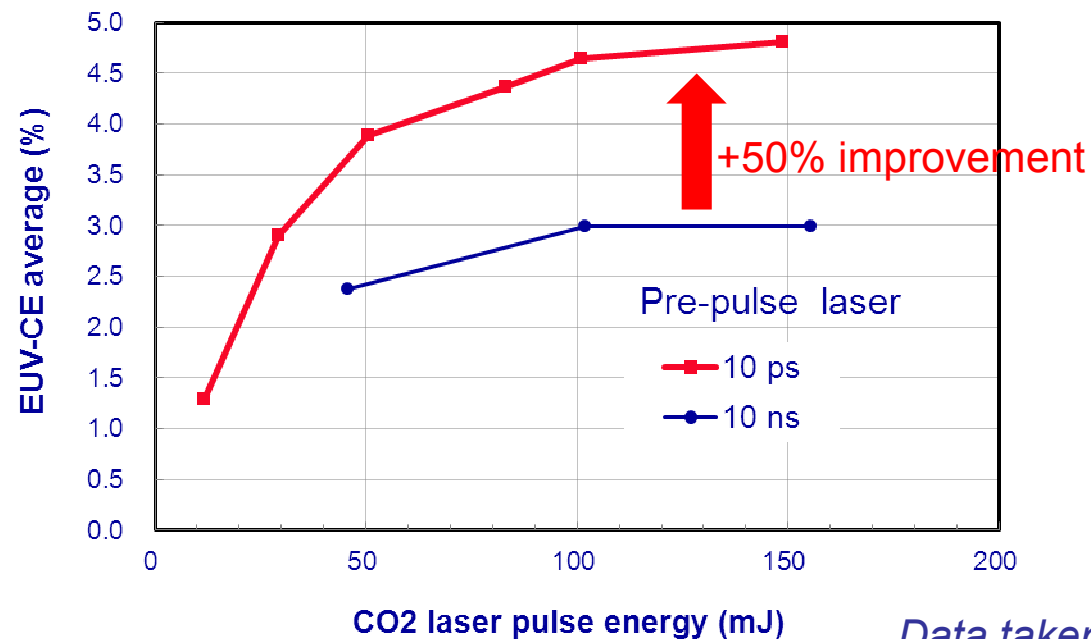
Technology update: Modeling of pre-pulse plasma



Technology update: High CE enabled by Prepulse optimization

- **CE= 4.7% (average)** was demonstrated by pre-pulse optimization

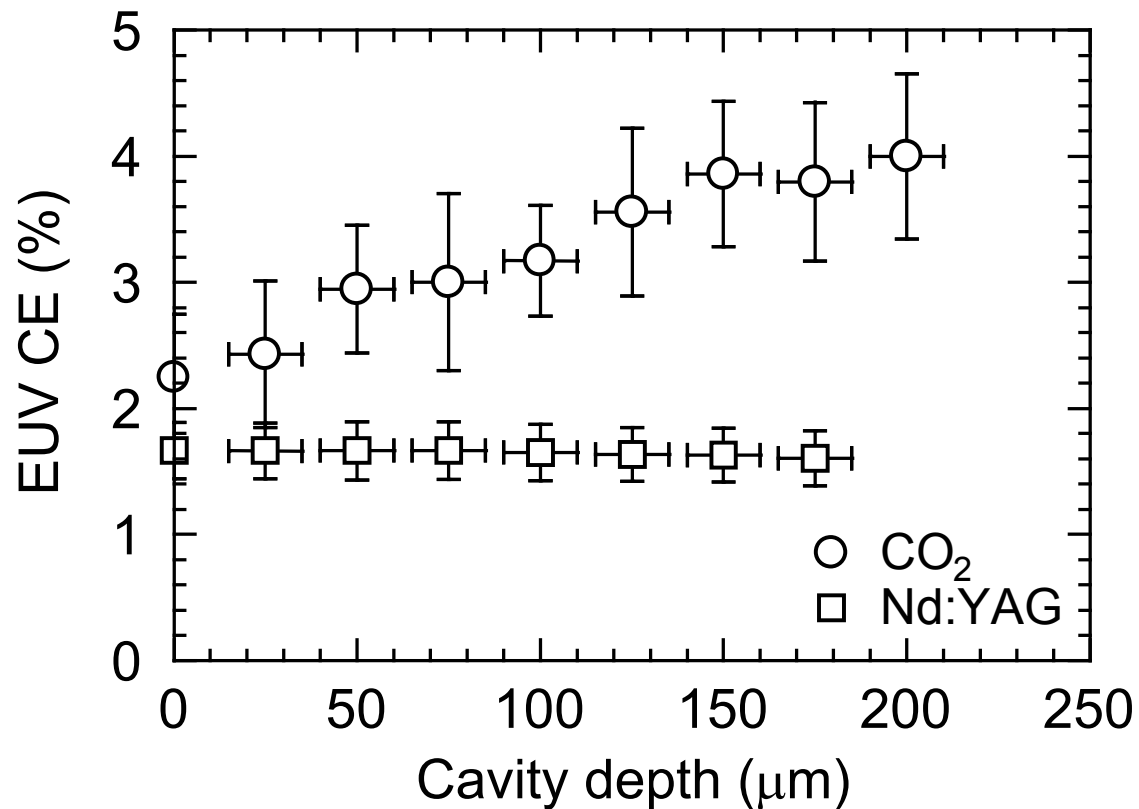
CO2 pulse energy vs. EUV-CE



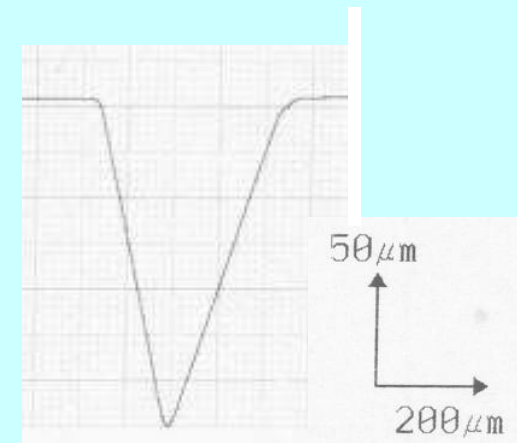
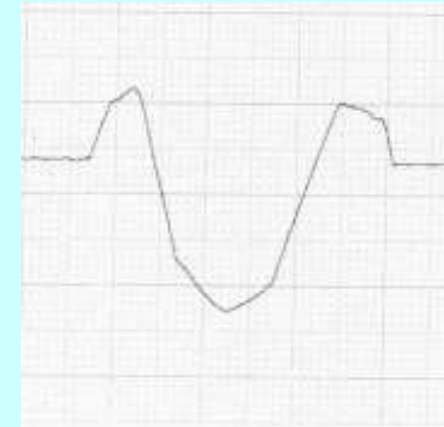
Data taken with low rep rate device at 2Hz

Mechanism of high CE and short pre-pulse duration is still under investigation

EUV conversion efficiency (solid target)

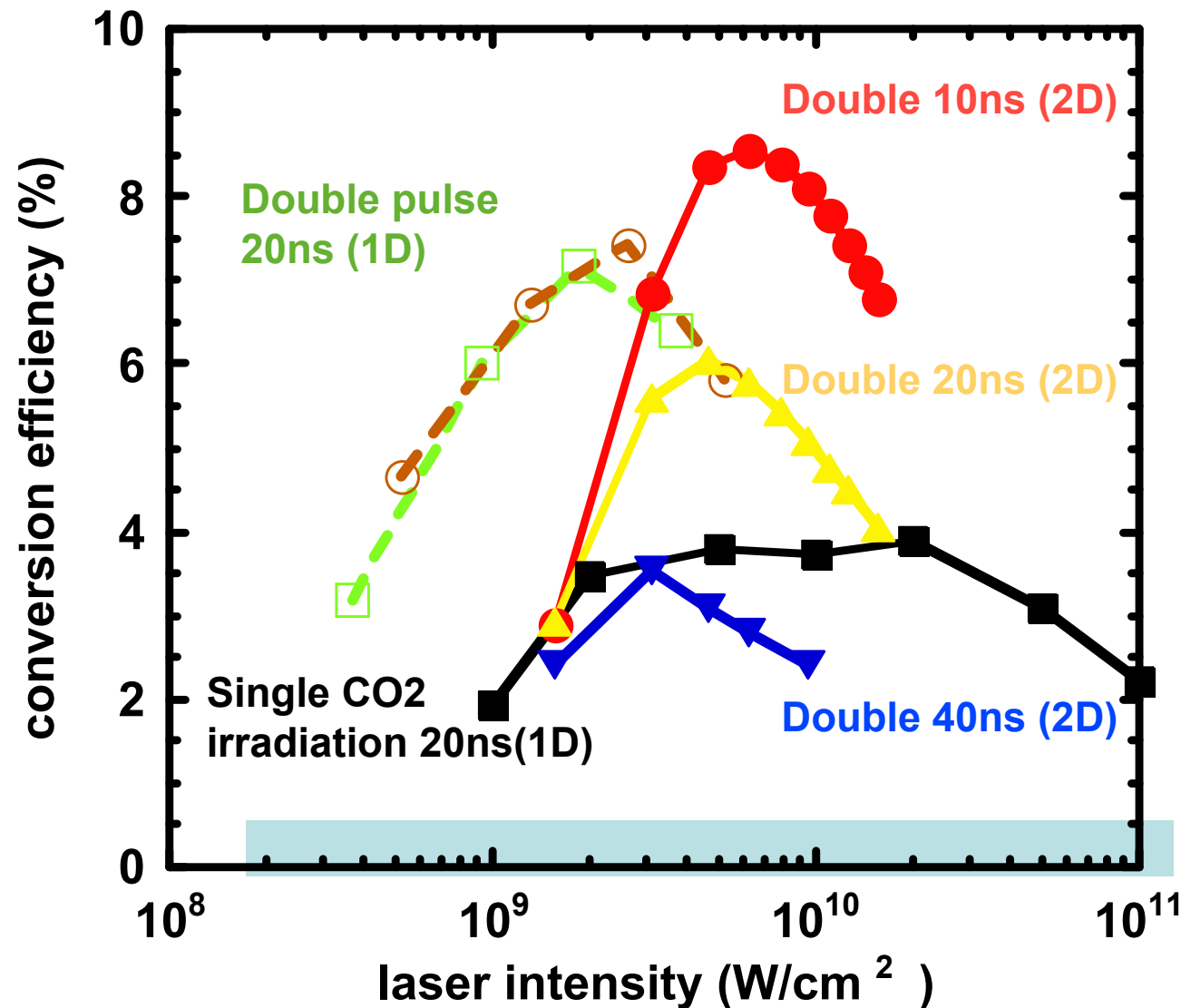


Cavity structure



We found Tin + CO₂ laser could be around 4% efficiency in 2008.

Simulation work cooperated with Osaka university

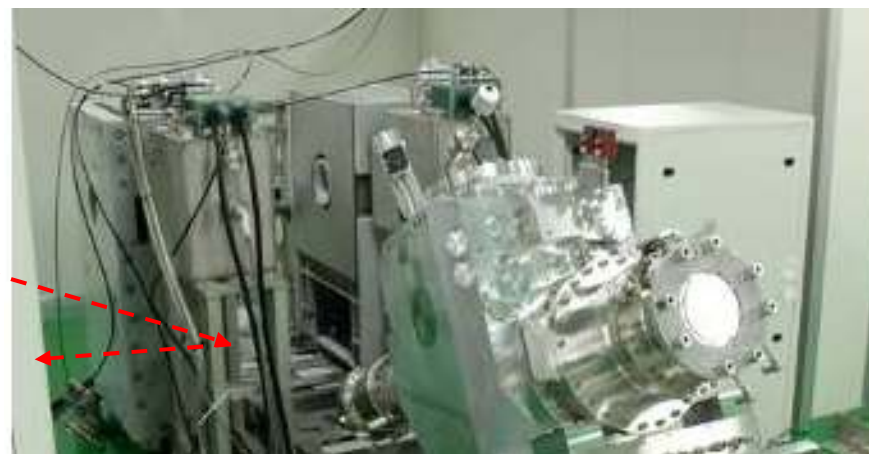
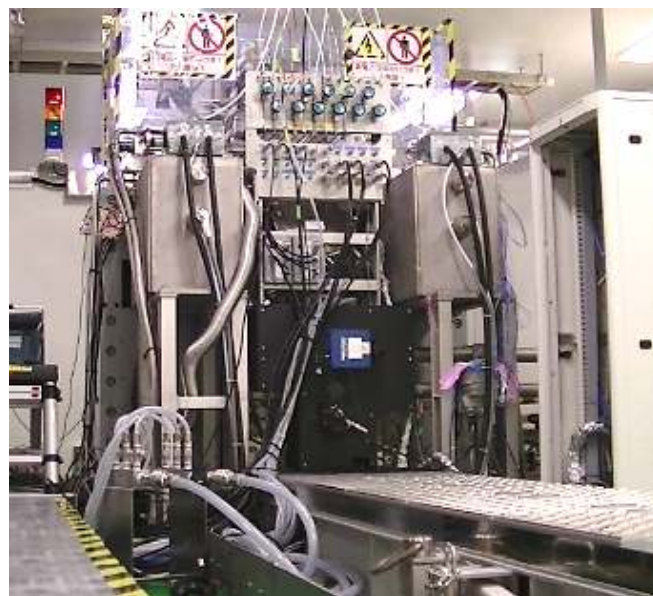
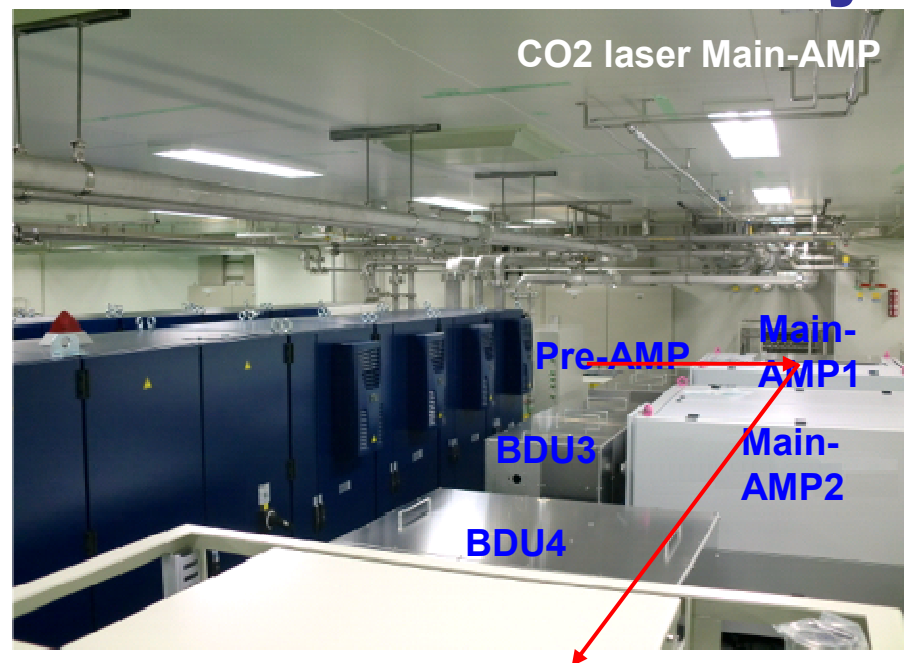


Pre-pulse
 $1 \times 10^8 \text{ W/cm}^2$
 10ns ($0.53 \mu\text{m}$)
 Time delay : 180ns
 In 2D simulation,
 $150 \mu\text{m}$ pre-formed
 plasma is initially set.
 Laser spot diameter:
 $800 \mu\text{m}$.

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GL200E proto constructed at Hiratsuka facility



Maximum 7W clean power at Proto system

➤ EUV light generated at Proto system

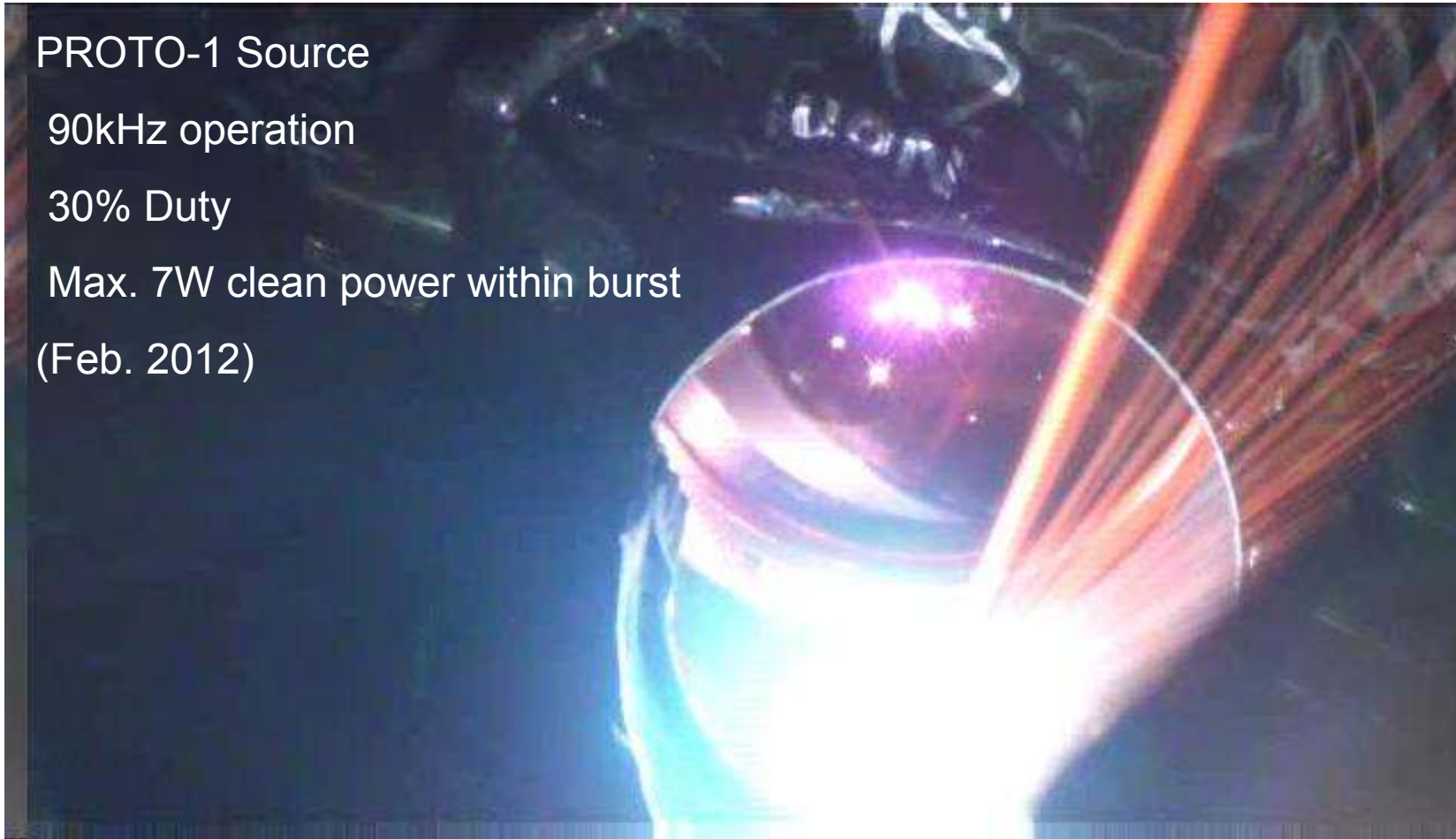
PROTO-1 Source

90kHz operation

30% Duty

Max. 7W clean power within burst

(Feb. 2012)



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➤ Proto-1

2011

➤ Proto-2

2012

- ✓ **Concentrate on solving Key technologies**
- ✓ **Improve above two challenges**
 - 50W stable operation during 1 week
 - Prove Maintainability and Availability

➤ Real-pilot

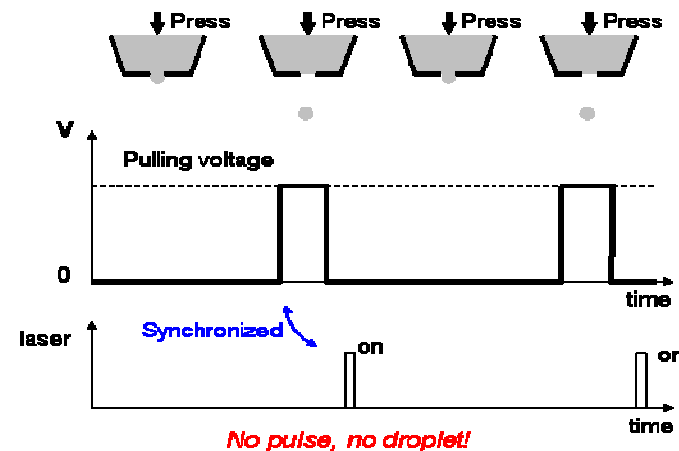
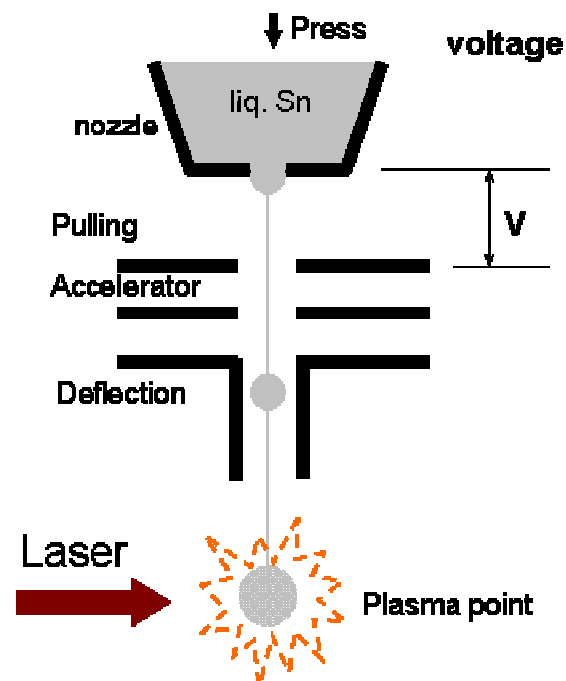
2013 -

Technology update: **PROTO-2**

➤ Target

1. Improvement of component technology
 - Newly designed “On Demand” droplet generator
 - Slab and Fast Axial Flow CO2 laser improvement
2. Stabilized EUV chamber
3. EUV 50W clean power & One week stable operation.

Droplet on Demand



Large controllability of droplet

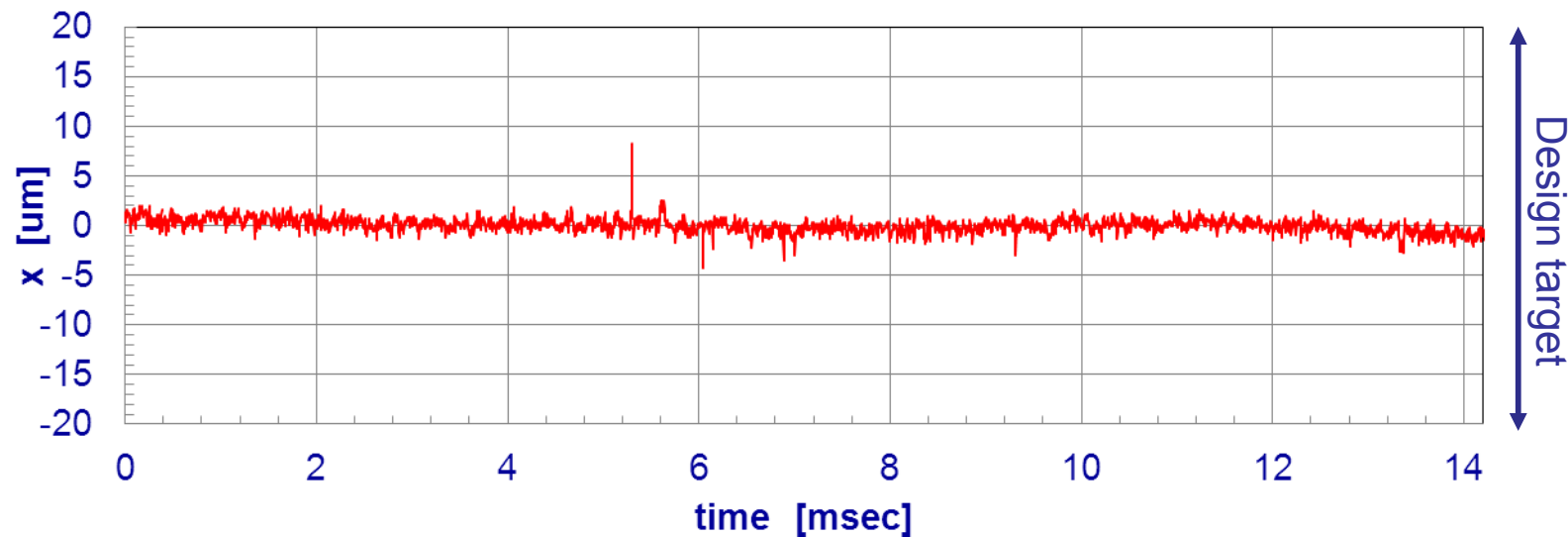
Droplet Parameters	Pressure	Voltage		
		Pulling	Accelerator	Deflector
Droplet size	✓	✓		
Timing		✓		
Speed			✓	
Direction X,Y				✓

Droplet on demand has an extensive capability to control all major key parameters

Technology update: Droplet Generator

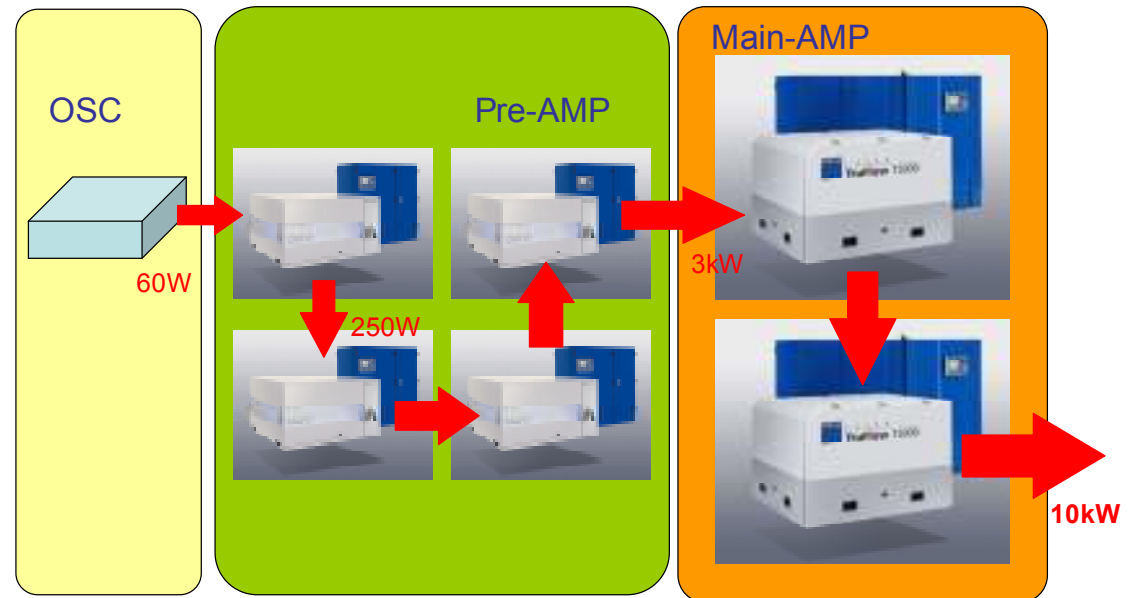
- Short term position stability is improved
- Droplet position is stable ($< \pm 10 \mu\text{m}$) over period of fast frame camera measurement range (14 msec)
- New shape nozzle performance meets design targets for shooting control

✓ **Short term stability:** $\pm 10 \mu\text{m}$ (target: $< \pm 20 \mu\text{m}$)



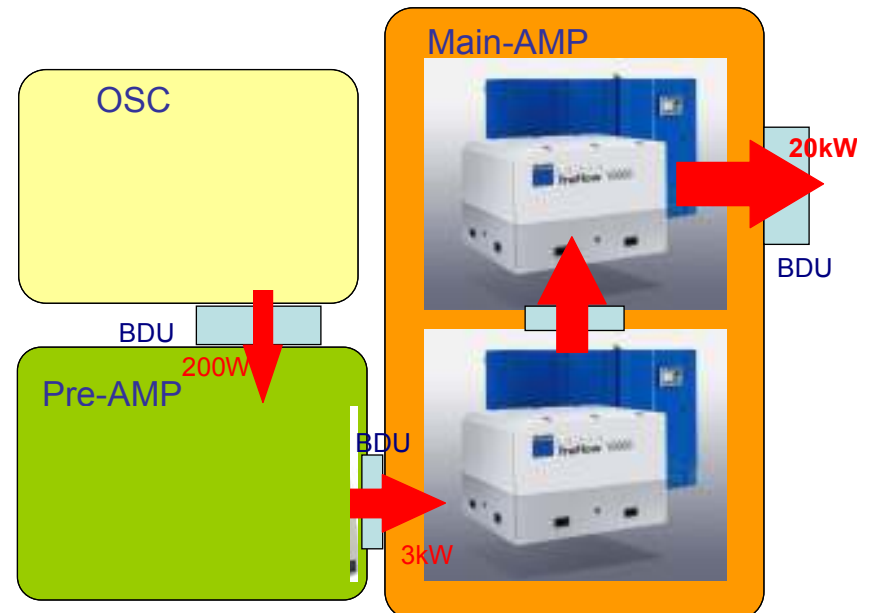
2nd gen. high power pulsed CO2 laser system

● 1st gen. laser system



● 2nd gen. laser system

- *Compact: footprint -> <50%*
- *Efficient: plug in eff. x2*
- *Higher power: 10kW-> 20kW*



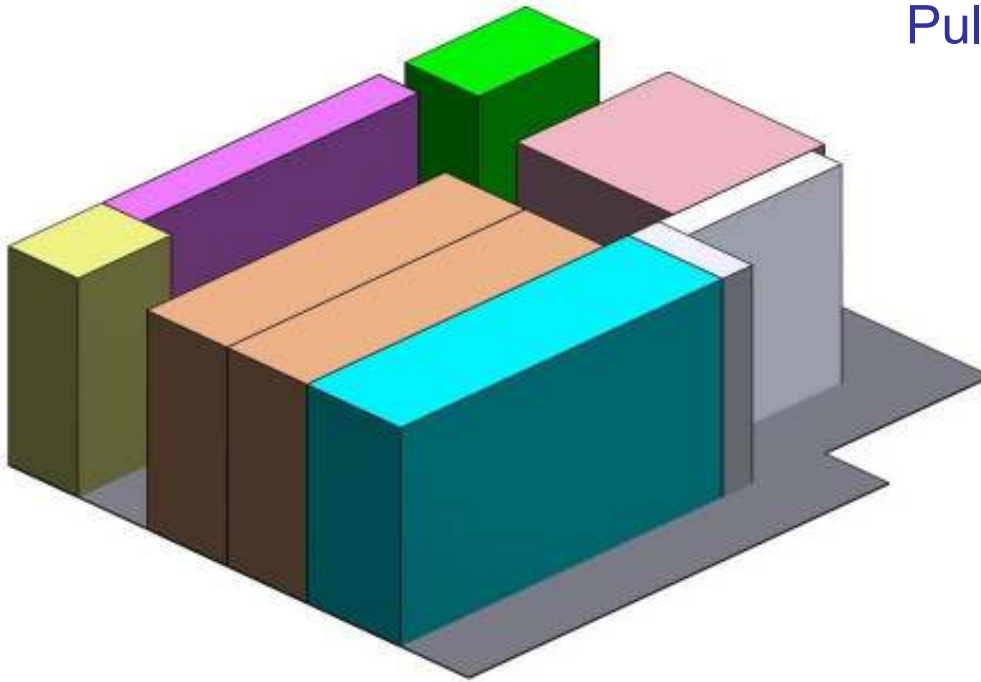
High power driver CO₂ laser Unit

Final target

Power target: 23kW

Repetition rate: 100kHz

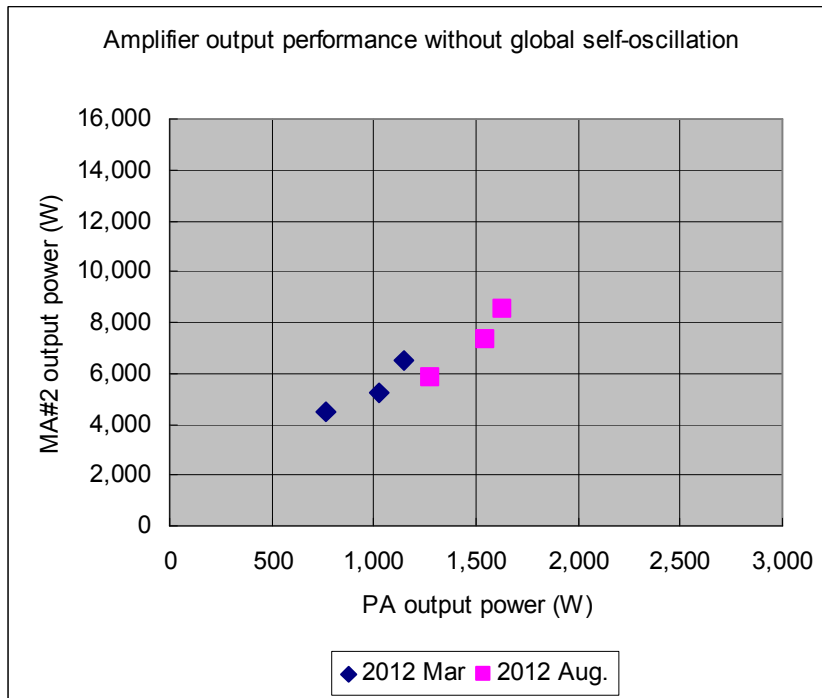
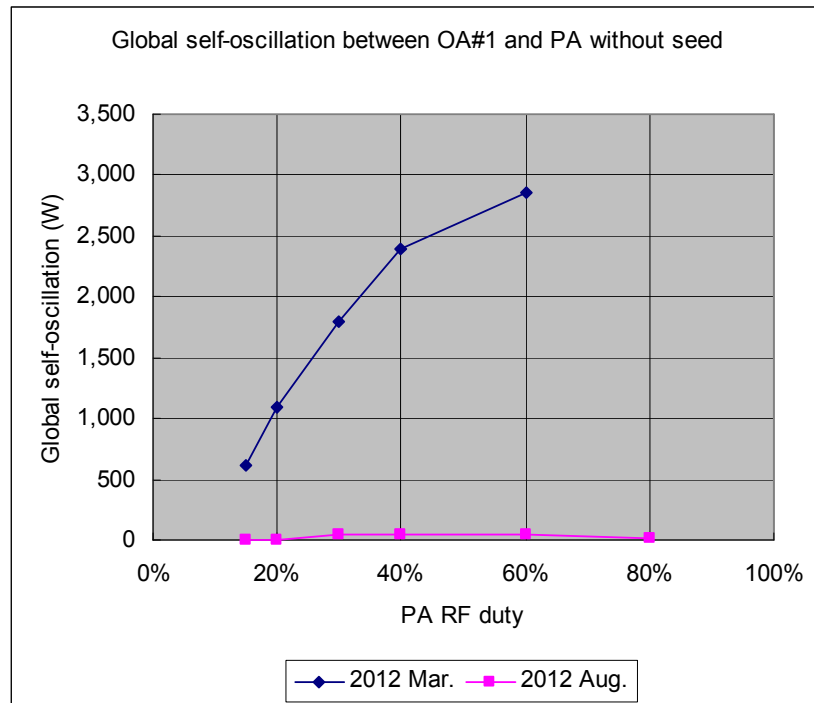
Pulse duration: 15ns



Technology update: CO₂ laser

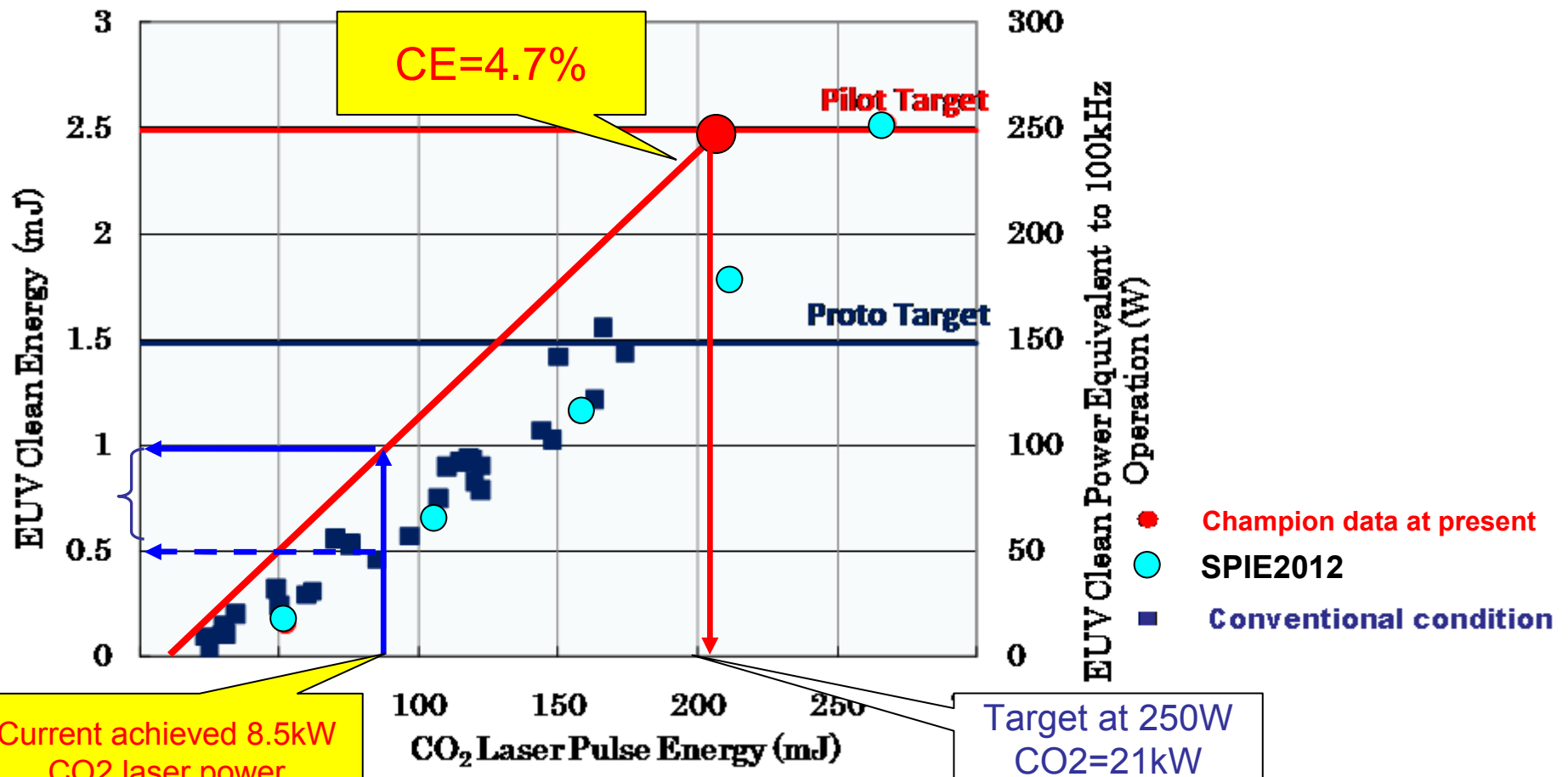
(Slab CO₂ + FAF CO₂ AMP. system)

- kW level global self-oscillation was improved to 50 W level. As a result, CO₂ power was improved from 6.5 kW to **8.5 kW**.
- > 10 kW power will be achieved by the following items.
 - ✓ Power improvement by optimization of gas exchange
 - ✓ Power improvement by input beam shape optimization
 - ✓ Multiline amplification.



EUV Output Power vs. CO2 Input Power

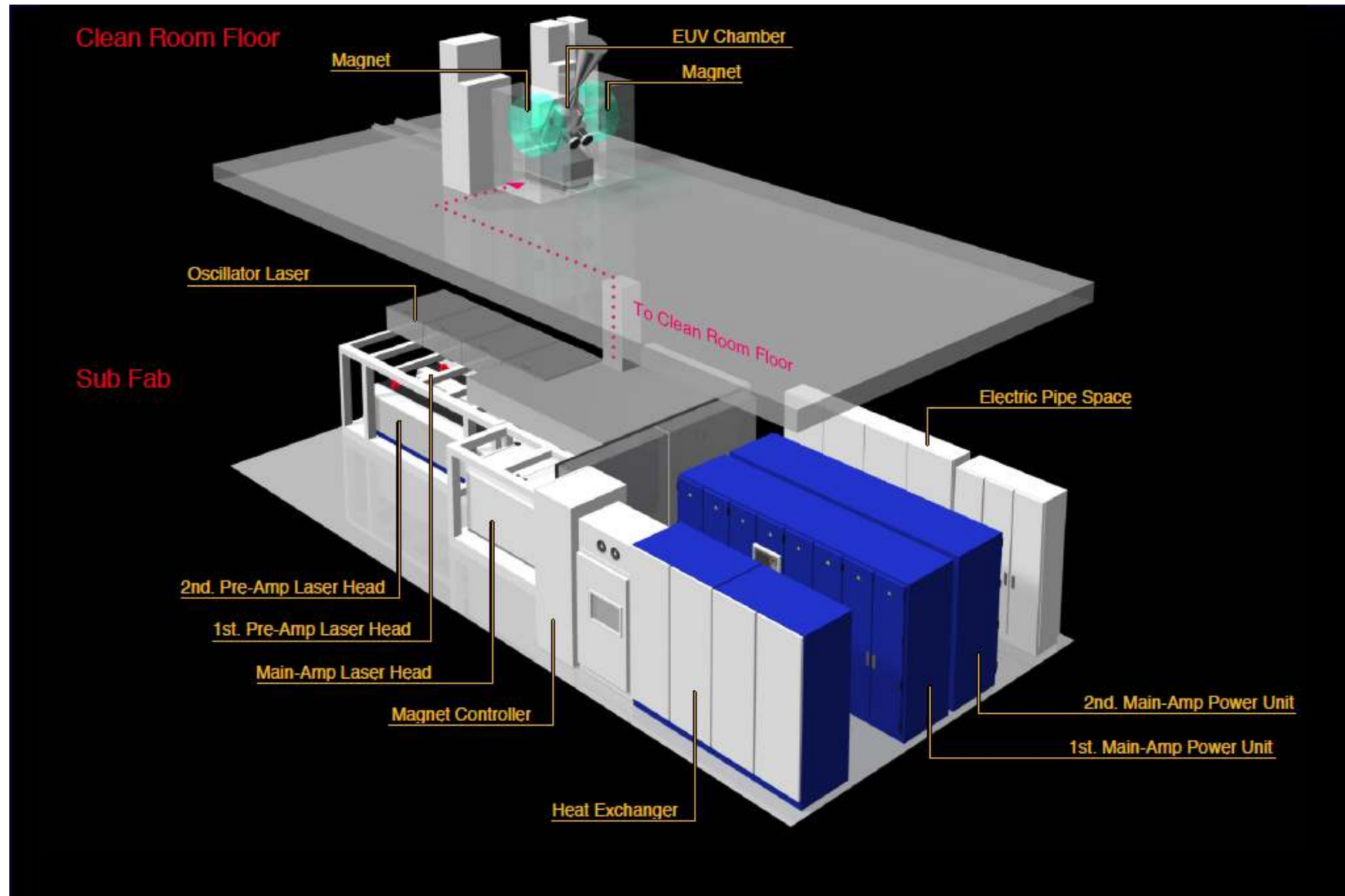
- We expect 2.5mJ EUV output corresponds to 250W clean power with CE >4.7%



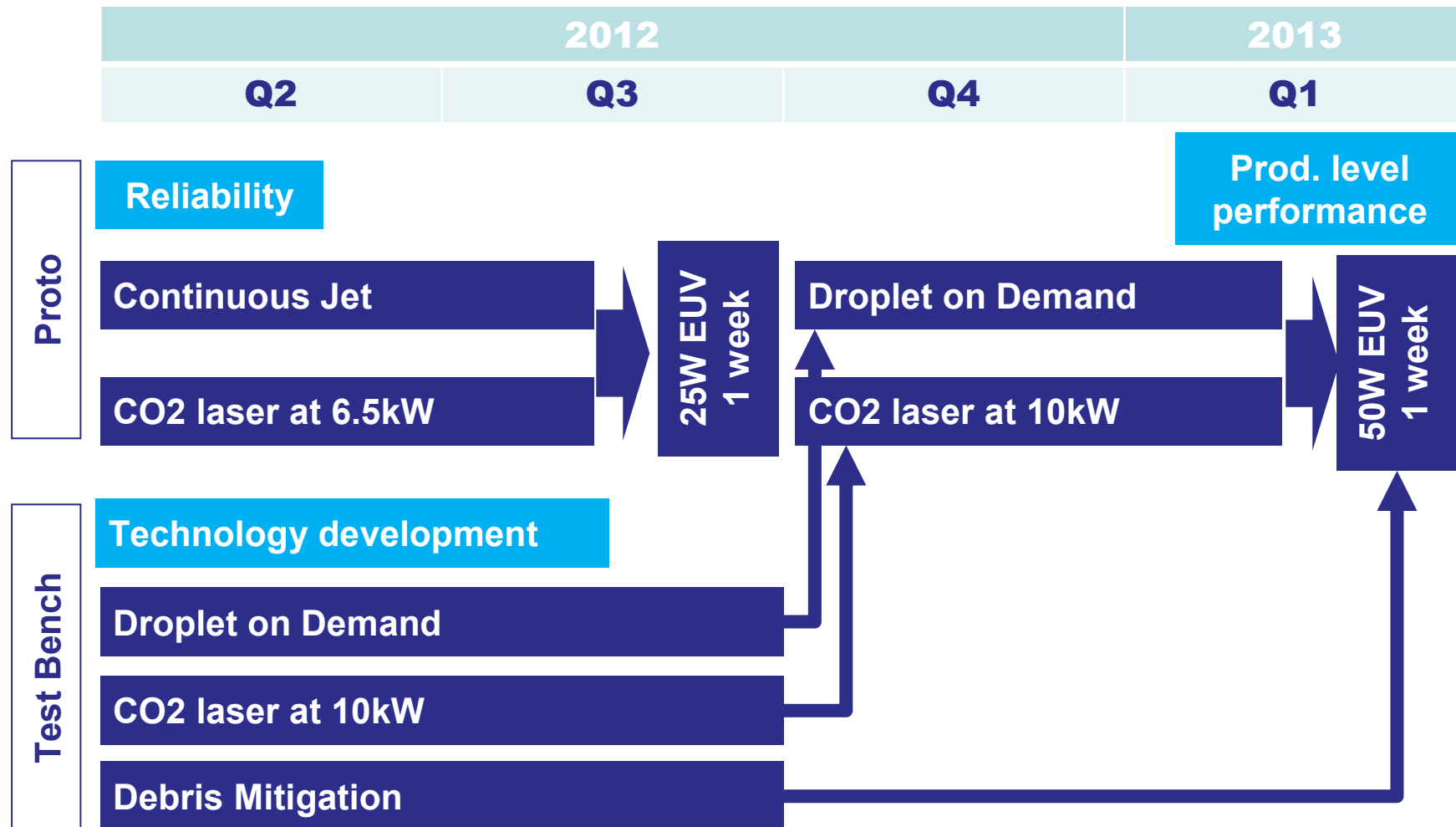
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- **Real-pilot** **2013 -**
 - ✓ **Restart product development**
 - ✓ **Integration test at customer site**

GL200E system (Real Pilot) overview



Development schedule overview 2012-2013



New Amplifier Development Project (poster P-SO-04)

Target: 40kW driver laser for future 500W EUV source with >500W

➤ Concept: Minimize electric consumption of driver laser system
by using superior high efficiency transverse flow CO₂ laser technology.

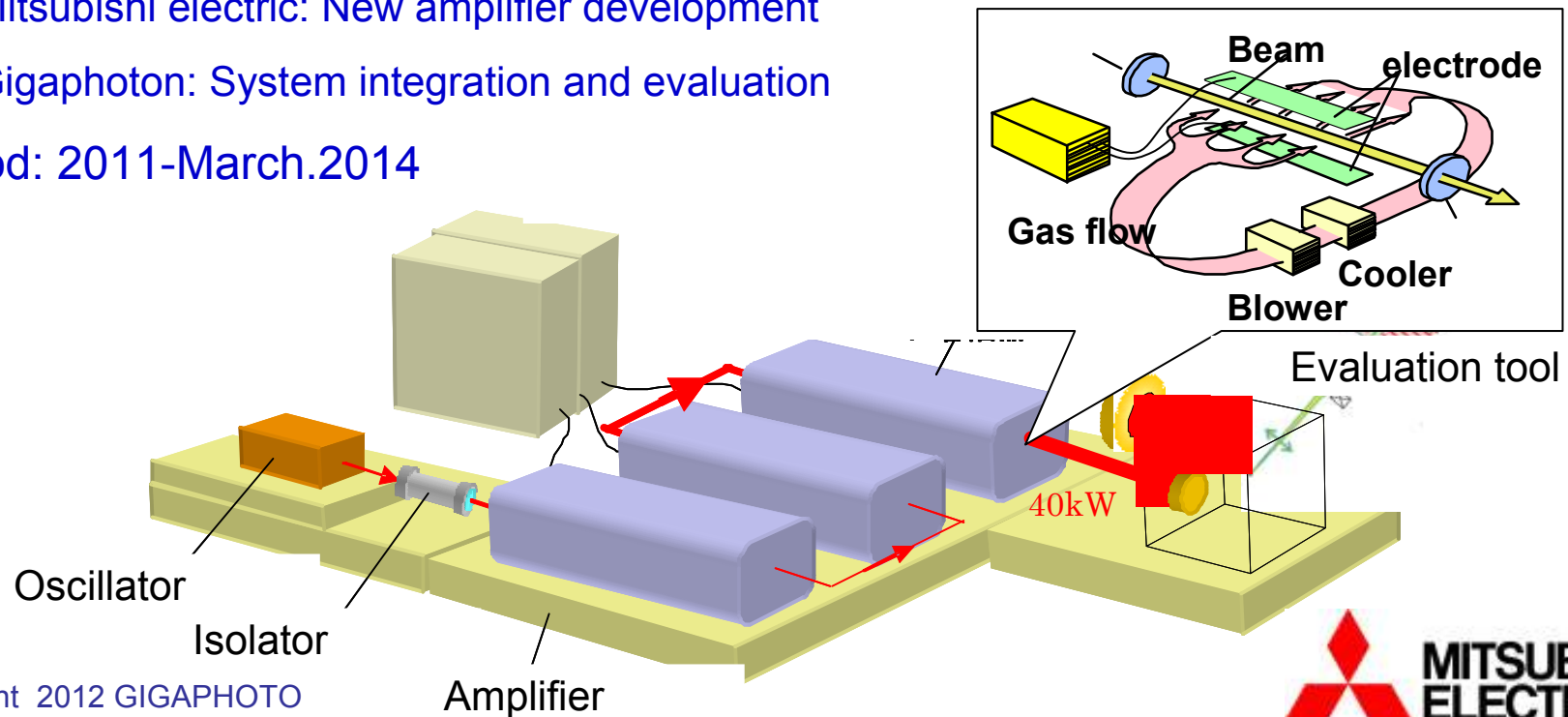
➤ Scheme: Lead by **Mitsubishi electric**

with technical support by Gigaphoton and funding support by NEDO

✓ Mitsubishi electric: New amplifier development

✓ Gigaphoton: System integration and evaluation

➤ Period: 2011-March.2014



Summary

- **1st generation integrated setup LPP source (ETS) and 10 Hz device:**
 - 10Hz experiment clarify CE (Conversion Efficiency) improvement, with <20 μ m droplet we found the region where **CE 4.7% average** with pico second pre-pulse, and perfect vaporization are simultaneously possible.
- **2st generation LPP source (GL200E):**
 - Proto-1, we observed 1st EUV light with 18W equivalent power (2011).
 - During proto-1 experiment we face two technical issues on DLG and CO2 laser. We changed the direction to solve these technical issues at first.
 - We developing Proto-2nd phase machine before commercialize the EUV source. The concept of the machine is reported.
 - **Droplet generator improvement is going on. Short term stability is in spec.**
 - **CO2 laser achieved 8.5kW operation with 75% duty.**
 - Proto-2 target is **50W level one week operation demonstration by 1Q 2013.**
- **New amplifier development project started** co-operation with Mitsubishi electric.
- We acknowledge EUV source development funding partial support by **NEDO.**

***Gigaphoton's Source make the End of
the EUV Tunnel!***

Thank you for your attention!